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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,262,334** on February 19, 1999, by **ICRON SYSTEMS INC.,** assignee of Juraj Krajci and Keith Kejser, for "Method and Apparatus for Extending the Range of the Universal Serial Bus Protocol".

S Gregoire
Agent certificateur/Certifying Officer

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Date

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Method and Apparatus for Extending the Range of the Universal Serial Bus Protocol

Field of the Invention

This invention relates to methods and apparatus for transmitting signals between devices using Universal Serial Bus ports, and, in particular, to an method for allowing communications between devices using such ports over an extended range.

Description of the Related Art

Universal Serial Bus (USB) is a new technology designed to permit a wide range of peripherals to be attached to personal computers by the average user. Since the technology supports all of the common peripheral devices such as keyboards, mice, speakers, modems, joysticks, cameras and many others, it will replace the serial and parallel ports in use today. The new Apple iMac (Trade Mark), for example, supports only USB ports. In addition, almost every personal computer (PC) manufactured since 1997 has been equipped with USB ports.

USB was created by an alliance of seven of the largest companies in the computer and communication markets. Those companies were Intel, Compaq, Microsoft, NorTel, NEC, Digital and IBM. The specifications defining USB (e.g. Intel et al., Universal Serial Bus Specification, Revision 1.0, January 1996; - hereinafter referred to as the "USB Specification") are non-proprietary and are managed by an open industry organization known as the USB Forum. The USB Specification establishes a number of criteria which must be met in order to comply to USB standards.

For example, it is a current requirement of the USB Specification that a single USB domain shall support up to 127 devices operating over a shared medium providing a maximum bandwidth of 12 Mbps.

Further, the USB Specification limits the distance that a device can be separated from its host PC to 5 meters. By using a series of USB Hubs – devices that are intended to support increased populations rather than increased distances – this distance limitation can be increased, in theory, to 30 meters. This multiple hub solution is both expensive and clumsy. For example, to support a single device at a range of 30 meters the consumer must purchase five hubs at a current cost of about $50 US each. In addition, at least two of these hubs must be provided with electrical power. Since the individual cables between hubs are limited to 5 meters each, it is also likely that some of the hubs would have to be positioned in very inconvenient and insecure locations.

There is therefore a need for methods and apparatus to allow USB devices to be positioned at greater distances from the host PC. For example, an uninterrupted distance of at least 100 meters is required for compatibility with the standards governing the cabling of commercial buildings (see, for example, TIA/EIA-568-A, Commercial Building Telecommunications Cabling Standard, Telecommunications Industry Association, October 1995). Meeting this standard must be accomplished without the need for intermediate repeaters since distribution cabling is not normally accessible between its end-points at, for example, the Telecommunications Closet and the Work Area. Furthermore, even if the cable were to be accessible, the cabling standard does not allow active devices to be inserted other than at the end-points.

Providing for an extended range capability would also create new applications for USB devices as well as facilitating existing ones. For example, a simple residential or SOHO (small office, home office) surveillance system could be constructed by connecting consumer quality cameras to a central PC. An overhead mounted monitor could be controlled by a remote keyboard or mouse. A door-phone entrance system could be monitored from any office in a commercial building.

Currently, however, the USB Specifications do not permit the use of extended ranges. For example, it is a further requirement of the USB Specification that the access of each device to the shared communications bus is controlled by a single Host Controller. It is also specified that when the Host Controller instructs a particular device to place its information onto the shared bus, the requested information must be received by the Host Controller within sixteen (16) bit-times of said Host Controller issuing said instruction. In practise, this ensures that the USB Specification provides for a high efficiency of bandwidth utilization by limiting the period during which no information is being transmitted. However, these requirements also limit the physical range of USB devices since one bit-time is equivalent to the time taken for an electronic signal to traverse approximately 17 meters of copper cable.

Further, although the USB device must respond to a request from the Host Controller within 16 bit-times, 7.5 bit-times is allocated for delay within a USB device and its associated 5 meter cable. This allocation retains only 8.5 bit-times for additional cable delay. The time represented by 8.5 bit-times is equivalent to the delay incurred by electronic signals in traversing approximately 144 meters of cable. However, this cable length is insufficient to satisfy the round-trip cable length of 200 meters required by the premise cabling specification.

Thus, it is not currently possible to provide USB devices which are separated over an extended distance.

However, it is a further feature of the USB Specification that the USB Specification (or protocol) segregates access to the shared bus into discrete units known as frames. Each frame is designed to last for a period of 1 ms.

Further, the current USB Specification also requires that at least four separate types of data streams or "traffic" are recognized, namely isochronous transfers, control transfers, interrupt transfers and bulk transfers. Of most interest in the present application, isochronous data transfer ensures that data flows essentially continuously, and at a steady rate, in close timing with the ability of the receiving mechanism to receive and use the incoming data. This type of data transfer is distinguished from asynchronous data transfer, which

pertains to processes that proceed independently of each other until a dependent process has to "interrupt" the other process, and synchronous, which pertains to processes in which one process has to wait on the completion of an event in another process before continuing. It should be noted that it is an aspect of isochronous transfers that timely delivery of information is ensured at the expense of potential transient losses in the data stream. In particular, there is no attempt to retransmit any data that may have been lost in previous transmissions. For example, with an isochronous video signal, loss of one frame of information is generally not significant, and there is no interest in retrieving the lost frame. Instead, the host controller is typically more concerned with receiving the current frame.

The current invention uses the fundamental characteristics of isochronous data, and more generally any data transmission where loss of data in previous transmission is of minor consequence, and the existence of regular protocol frames in order to provide methods and apparatus to enable data transmission over extended distances.

Accordingly, while USB technology has proven to be useful, it would still be desirable to provide improvements to the technology by providing a method and apparatus for enabling data transmission equipment, and in particular, data transmission equipment utilizing the USB Specification, to be used over an extended range.

Therefore, it is an object of the present invention to provide methods and apparatus to enable devices, hubs and controllers and other devices that conform to the USB Specification to communicate over distances greater than that currently permitted under said USB Specification.

It is a further object of the present invention that such extended range be achieved without the need for intermediate hubs, repeaters or other methods of electronic signal regeneration.

It is a further object of the present invention that no hardware or software changes need be made to the existing devices, hubs and controllers supported by the system, and in particular, an isochronous system operating under the

USB Specification. The invention, thereby, may be incorporated into networks composed of both conventional range and extended range devices.

It is a further object of the present invention that the apparatus be very cost effective, consistent with the broadest population of devices targeted by the USB industry.

These and other objects of the invention, which will become apparent herein, are attained by the present invention as described hereinbelow.

Summary of the Invention

Accordingly, the present invention provides a method for transmitting a time relevant data stream, and in particular an isochronous data stream, between a host controller and a peripheral device over an extended distance; said method comprising:

a. feeding a first original, outgoing digital signal from a host controller to a local expander unit;
b. optionally converting said outgoing digital signals into a converted outgoing signal having a format suitable for transmission over extended distances;
c. transmitting either said outgoing digital signal or said converted outgoing signal, as a outgoing transmission signal, over a signal distribution system;
d. receiving said outgoing transmission signal at a remote expander unit;
e. optionally converting said outgoing transmission signal to said first original outgoing digital signal;
f. delivering said first original outgoing digital signal from said remote expander to at least one peripheral device;
g. receiving, at said remote expander, a reply digital signal from said peripheral device;
h. optionally converting said reply digital signal into a converted reply signal having a format suitable for transmission over extended distances;

i. transmitting said reply digital signal or said converted reply signal as a reply transmission signal over said signal distribution system;

j. receiving said reply transmission signal at said local expander;

k. optionally converting said reply transmission signal to said original reply digital signal;

l. storing said reply digital signal as a stored reply digital signal until the receipt of a subsequent original, outgoing digital signal from said host controller, which subsequent signal is the same as, or similar to, said first original outgoing digital signal; and

m. forwarding said stored reply digital signal to said host controller in response to said subsequent original outgoing digital signal.

For the purposes of the present specification, the term "time relevant data" is meant to relate to data streams such as isochronous data streams wherein loss of a frame from a previous transmission is of minor consequence and therefore, does not need to be retransmitted.

In a preferred embodiment, all digital signals conform to the USB Specification (other than for the distance between devices), and all digital signals, and in particular, the reply digital signal, represent isochronous data. Further, in a preferred embodiment, the extended distance exceeds 5 meters, more preferably, exceeds 30 meters, and still more preferably, exceeds 100 meters. In particular, the distance between the local expander and the remote expander exceeds 5 meters, more preferably, exceeds 30 meters, and still more preferably, exceeds 100 meters.

While a number of different signal distribution systems might be used, preferably, the signal distribution system utilizes unshielded twisted pair (UTP) wiring (or cabling).

In a further preferred embodiment, the present invention provides a method for transmission of isochronous data according to the USB Specification wherein isochronous data is transmitted from a peripheral device and is received by a host controller, said method comprising:

a. Transmitting a request for isochronous data from a host controller to a local expander;
b. Forwarding said request for isochronous data from said local expander to a remote expander over a signal distribution system;
c. Delivering said forwarded request for isochronous data to at least one peripheral device;
d. Transmitting the requested isochronous data from said peripheral device to said remote expander;
e. Forwarding said requested isochronous data from said remote expander to said local expander over said signal distribution system;
f. Storing said requested isochronous data in a packet buffer at said local expander;
g. Transmitting a subsequent request for isochronous data from said host controller to said local expander;
h. Receiving said subsequent request for isochronous data at said local expander; and
    I. Retrieving the stored isochronous data from said local expander;
    II. Delivering said stored isochronous data to said host controller;
    III. Forwarding said subsequent request for isochronous data from said local expander to said remote expander over said signal distribution system; and
    IV. Repeating steps (c) through (h) for said subsequent request and any further subsequent requests for isochronous data.

In an even more preferred embodiment, the present invention provides a method additionally comprising the following steps after item "a" described hereinabove, namely:

i. Determining whether said local expander already possesses said requested isochronous data;
ii. Generating a synthetic data packet if no such requested isochronous data is present; and
iii. Delivering said synthetic isochronous data to said host controller.

One method for generating the synthetic data packet is described hereinbelow.

In another aspect, the present invention also provides an apparatus for transmission of a digital signal over an extended distance comprising:

a local expander comprising means for receiving a request for a time relevant data signal, and preferably an isochronous data signal, from a host controller which host controller is connected to said local expander;

means in said local expander for generating an outgoing transmission signal;

means in said local expander for sending said outgoing transmission signal to a remote expander, which signals are sent over a signal distribution system;

a remote expander comprising means for receiving said outgoing transmission signal;

means in said remote expander for generating a digital signal from said outgoing transmission signal;

means in said remote expander for forwarding said digital signal to at least one peripheral device, which peripheral device is connected to said remote expander;

means in said remote expander for receiving inbound digital signals from said peripheral device;

means in said remote expander for converting said inbound digital signals to an inbound transmission signal;

means in said remote expander for sending said inbound transmission signal to said local expander, which signals are sent over said signal distribution system;

means in said local expander for receiving said inbound transmission signal;

means in said local expander for generating a digital signal from said inbound transmission; and

means in said remote expander for forwarding said digital signal to said host controller.

Preferably, the local expander additionally comprises:

means for storing said inbound signal as a stored inbound signal;

means for analysing said digital signal from said host controller to recognize a subsequent request for transmission of said time relevant digital signal; and

means for sending said stored inbound signal to said host controller in response to said subsequent request.

Description of the Preferred Embodiments

Although a number of signal distribution systems may be used, as described hereinabove, preferably the signals are transmitted over a signal distribution system which utilizes Unshielded Twisted Pair (UTP) copper wire. Using this method of device connection provides a low cost, effective means for data transmission. However, in another embodiment of the system, signals can be transmitted over coaxial cable.

While the methods and apparatus of the present invention have general utility in a variety of applications, it is of primary importance that the data transmission methods and apparatus of the present invention allow for compliance with the USB Specifications. Preferably, the original signal from the host controller is a request for data from a peripheral device. Additionally, preferably the data requested is isochronous data from peripheral devices such as cameras, keyboards, mice, monitors, speakers, and the like.

In particular, during operations utilizing the methods and apparatus of the present invention in applications involving extended range transmissions, it is preferred that the apparatus be preferably capable of recognizing isochronous transfers, when they are received. The data contained within the isochronous transfer is then stored within the system for a period of time. Accordingly, the

data that is received during a particular frame may be stored and then transmitted in a following frame. Additionally, a further preferred embodiment of the present invention is that isochronous transfers originating from a plurality of sources may be stored, and retransmitted.

In the operation of a preferred embodiment of the current invention, a host controller (which preferably is a PC) may issue a request to a device for the transfer of isochronous data. The request is received by the apparatus of the present invention, and retransmitted to the target device. When the requested isochronous transfer response is received by the apparatus from the target device, the isochronous data is stored within the internal memory of the apparatus. During a subsequent frame, the host controller will again issue a request to the target device for the transfer of isochronous data. The apparatus will again retransmit this request to the target device. In addition, however, the apparatus recognizes that it currently has isochronous data from the target device stored in its internal memory. The apparatus sends this data to the host controller within the 16 bit-time margin relevant to the current request within the current frame. In this manner, the apparatus uses data collected in a previous frame to satisfy the response time requirement of a current frame.

When a packet is received from the target device, and no further request for data is received from the host controller, the last data packet or packets received and stored (hereinafter the "vestigial" packets) are preferably removed from the system so that they are not transmitted when and if a further request is received from the host controller. Preferably, this is achieved by modification of the method described hereinabove by additionally comprising the following stages, namely:

i) Detecting when a new frame has begun;

ii) Examining the properties of each packet buffer;

iii) Determining whether the data packet contained in said examined packet buffer has been stored for at least one complete frame period;

iv) Discarding said contained data packet if said contained data packet has been stored for at least one complete frame period; and

v) Repeating steps (i) through (iv) for each packet buffer in the system.

In an alternative embodiment of the invention, the apparatus handles the first request for the inbound transfer of isochronous data in a unique manner. This unique manner requires the apparatus to generate its own synthetic inbound data packet, and generation of this synthetic data packet is described hereinbelow.

It is possible that packets sent from the Remote Expander may not arrived at the Local Expander in the order expected by the Local Expander. In order to avoid difficulties which might be caused by this occurrence, the method of the present invention also preferably comprises the following stages, namely:

i) Storing the address of the requested peripheral device at said remote expander unit after the local expander has delivered the forwarded request for isochronous data;

and further comprising the following steps after transmitting the requested isochronous data from the peripheral device to the remote expander, namely:

i) Retrieving the address of said requested peripheral device at said remote expander unit; and

ii) Adding said retrieved address to said requested isochronous data.

By utilizing the method and apparatus of the present invention, it is possible to have transfer of time relevant data, and isochronous data in particular, over extended distances, and in particular, over distances greater than specified in the USB Specification.

Brief Description of the Drawings

The invention, and various aspects thereof, will be described by reference to the attached drawings wherein:

Figure 1 is a PC equipped with conventional USB Hub and USB Devices;

Figure 2 is a PC equipped with Extended Range Hub and USB Devices according to the present invention;

Figure 3 is a schematic drawing of an embodiment of the invention designed to operate using UTP wiring as a signal distribution system;

Figure 4 is a timing diagram showing isochronous transfers according to the USB protocol;

Figure 5 is a timing diagram showing isochronous transfers according to the current invention;

Figure 6 is a schematic drawing of an embodiment of a Local Expander according to the invention;

Figure 7 is a schematic drawing of an embodiment of a Remote Expander according to the invention;

Figure 8 is a sequence diagram showing an isochronous input transfer according to the invention;

Figure 9 is an alternative isochronous input transfer according to the invention;

Figure 10 is a sequence diagram showing an isochronous output transfer according to the invention;

Figure 11 is a logic diagram of a LEX controller according to the invention;

Figure 12 is a logic diagram of an enhanced LEX controller according to the invention;

Figure 13 is a logic diagram of a further enhancement to the LEX Controller enabling vestigial packets to be removed;

Figure 14 is a logic diagram of a REX controller according to the invention; and

Figure 15 is a logic diagram of an enhanced REX controller according to the invention.

In the drawings, Figure 1 shows a PC (1) equipped with two conventional USB Hubs (2a & 2b), and four standard USB Devices (3a, 3b, 3c & 3d). The length of cable between the two hubs (2a and 2b) cannot exceed 5 meters according to the current USB Specification.

Figure 2 shows a PC (1) equipped with an apparatus according to the present invention, which is termed as an "Extended Range Hub" (7), and four standard USB Devices (3a, 3b, 3c & 3d). The Extended Range Hub is composed of two separate units, a "Local Expander" (4) and a "Remote Expander" (5) connected by cable (6). In one embodiment of the invention, units 4 and 5 can be separated by, for example, up to 200 meters of Category 5 UTP cable (6).

Figure 3 illustrates an embodiment of the invention designed to operate over UTP. In this embodiment, the functions normally provided by a USB Hub are provided by two separate units connected by a length of Unshielded Twisted Pair (UTP) copper wiring (6a). A Host PC may be connected to the first unit (4), referred to as Local Expander (LEX). The second unit (5) is referred to herein as Remote Expander (REX). REX (5) may be connected to a plurality of USB devices. In this embodiment said plurality is chosen to be four, but it will be clear to those skilled in the art that other choices may be made within the scope of the invention.

Operation over extended distances is preferably achieved by placing said LEX Unit (4) close to said host PC, placing said REX unit (5) close to said plurality of USB devices, and connecting LEX unit (4) and REX unit (5) by the required extended length of UTP cabling (6a).

Figure 4 provides a timing diagram showing isochronous transfers according to the USB protocol. The diagram is constructed from the point of view of a USB Host Controller, normally included on a PC motherboard (Host PC). The USB protocol divides time allocation on the shared bus into regular "frames", each of 1 ms in duration. The start of each frame is identified on the diagram as F1, F2, F3 & F4. When a Host Controller is engaged upon an isochronous transfer with a device, the Host Controller issues regular requests for data transfer to said device. These requests are identified in Figure 4 as packets R1, R2 & R3 (10, 12 & 14). Under the USB protocol, a USB device must respond to said request within 16 bit-times. The responses are shown in the diagram as packets Is1, Is2 & Is3 (11, 13 & 15). It is commonly expected that transfer Is1 (11) will be delivered in response to request R1 (10), transfer Is2

(13) will be delivered in response to request R2 (12), and so on until the requests are terminated.

Figure 5 provides a timing diagram showing isochronous transfers according to the present invention. The diagram shows the progression of packets through the various subsystems comprising the invention. Timelines are presented for the Host PC (1), Local Expander (LEX) (4) and Remote Expander (REX) (5) components which were shown in Figure 2.

An isochronous transfer is initiated from a Host PC (1) by emitting a request for input data R1 (20) to a particular USB address and end-point. Said request R1 (20) is received by the LEX (4) and retransmitted as R1 (25) over the external cabling to the REX (5). Said retransmitted packet R1 (25) is received by the REX (5) and forwarded as R1 (31) to the target device (e.g. one of items 3a, 3b, 3c or 3d of Figure 2).

The target device generates an input data packet Is1 (32). According to the USB protocol, a device without an integrated cable must generate a response within 6.5 bit-times of the end of the corresponding request. Said input data packet Is1 (32) is received by the REX subsystem (5) and retransmitted as Is1 (26), over the external wiring, to the LEX (4). Said retransmitted response Is1 (26) is not immediately forwarded to the Host PC (1), but is stored within the memory of the LEX subsystem (4).

The Host PC (1) notices that it did not receive a response to its input data request R1 (20), and retries the transaction by generating a new request R2 (21) to the same USB address and end-point. Upon receiving request R2 (21), the LEX subsystem 4 retrieves response Is1 (26) from its memory buffers and forwards it to the Host PC as response Is1 (22).

Said second request R2 (21) is repeated as R2 (27) through the LEX and forwarded as R2 (33) to the device. The target device generates a second response Is2 (34) which is retransmitted as Is2 (28) by the REX to the LEX. Response Is2 (28) is again stored within the memory of the LEX subsystem, from where it is sent to the host PC (1) as response Is2 (24) to a third request R3 (23). The process is repeated as necessary with requests R3 (23), R3 (29) and R3 (35) and responses Is3 (36) and Is3 (30).

Figure 6 illustrates one embodiment of a Local Expander (LEX) (4) according to the invention. Said embodiment comprises four major blocks. The USB Interface (50) enables a Host PC to be connected to the unit using standard USB cabling. Said USB Interface (50) receives signals in USB format from said Host PC and delivers USB packets to a LEX Controller (51). Said LEX Controller (51) determines what response is necessary to the received packet and generates the appropriate USB packets. If said LEX Controller (51) requires information to be stored prior to transmission, then said information is stored in RAM (53).

Information that must be sent to the Remote Expander (REX) (5) is forwarded to the UTP interface (52) wherein the information is converted into digital signals suitable for propagation over copper cabling.

In the reverse direction, digital signals originating from the Remote Expander (5) are received by UTP interface (52) and forwarded to LEX Controller (51). Said LEX Controller (51) saves any necessary information in RAM (53) and generates the required responses. Information that must be sent to the Host PC is transferred to the USB Interface (50), from where it may be forwarded to said Host PC using standard USB hardware and protocols.

Figure 7 illustrates an embodiment of a Remote Expander (REX) (5) according to the invention. Said embodiment comprises a UTP Interface (60), a plurality of USB Interfaces (63, 64, 65 and 66), a REX Controller (61) and a RAM (62). Operation of the REX (5) is similar to that of the LEX (4).

Figure 8 provides a sequence diagram showing an isochronous input transfer according to the invention. The format used in the diagram is attributable to Jacobson et al. (Ivar Jacobson, Magnus Christerson, Patrick Jonsson and Gunnar Overgaard, Object-Oriented Software Engineering: A Use Case Driven Approach, Addison-Wesley, 1992).

In Frame 1, the control logic (100) within the Host PC generates a request for input data, addressed to a particular USB function. Said request is transmitted to the LEX subsystem as an "In Addr" packet. The control logic (101) within the LEX subsystem forwards the In Addr packet to the REX subsystem.

The control logic (102) within the REX subsystem forwards the In Addr packet to the Device.

The control logic (103) within the device assembles the requested isochronous data and transmits it as a "Data Payload" packet to the REX subsystem. The control logic (102) within the REX subsystem forwards the Data Payload packet to the LEX subsystem. The control logic (101) in the LEX subsystem stores the Data Payload packet in its buffer memory.

In Frame 2, the control logic (104) within the Host PC recognizes that it has not received a response to its previous request for input data. Said control logic automatically retries the transaction by generating a further request addressed to the same USB function as in Frame 1. Said further request is transmitted to the LEX subsystem as a second In Addr packet. On receipt of the second In Addr packet, the control logic (105) within the LEX subsystem recognizes that it has a Data Payload packet stored in memory from the same function identified by the further In Addr packet. Said control logic (105) retrieves said stored packet from memory and transmits same to the Host PC. Said control logic (105) also forwards the new In Addr packet to the REX subsystem. The control logic (106) within the REX subsystem forwards the In Addr packet to the Device.

The control logic (107) within the device assembles the requested isochronous data and transmits it as a Data Payload packet to the REX subsystem. The control logic (106) within the REX subsystem forwards the Data Payload packet to the LEX subsystem. The control logic (105) in the LEX subsystem stores the Data Payload packet in its buffer memory.

The above-described process is repeated for subsequent frames by the distributed control logic (e.g. 108, 109, 110 & 111).

Figure 9 provides a sequence diagram showing an alternative isochronous input transfer according to the invention. This method differs from that described in Figure 8 in the manner in which the first request for an isochronous input transfer is handled.

In Frame 1, the control logic (100) within the Host PC generates a request for input data, addressed to a particular USB function. Said request is

transmitted to the LEX subsystem as an In Addr packet. The control logic (101) within the LEX subsystem forwards the In Addr packet to the REX subsystem as in Figure 9.

At this point in the sequence, an additional step is introduced. Said control logic (101) within the LEX subsystem generates a synthetic data packet and transmits it as a Data Payload packet to the Host PC. Said synthetic data packet is labelled Data Payload_0 in Figure 9. The remainder of the protocol handling continues as described in Figure 8.

The USB specification defines a DATA packet as being composed of a single byte Packet Identifier (PID), a Data Payload ranging in size from 0 bytes to 1023 bytes, and a Cyclic Redundancy Check of 2 bytes. Said synthetic data packet can therefore be constructed by assembling a data packet containing a zero length payload. Said synthetic data packet can thereby be used to satisfy the timing requirements of the USB protocol while causing no disturbance to the actual information being carried by the protocol.

Figure 10 provides a sequence diagram showing an isochronous output transfer according to the invention.

In Frame 1, the control logic (120) within the Host PC generates a notification of output data, addressed to a particular USB function. Said notification is transmitted to the LEX subsystem as an Out Addr packet. The control logic (121) within the LEX subsystem forwards said Out Addr packet to the REX subsystem. The control logic (122) within the REX subsystem forwards said Out Addr packet to the Device. The information is received by the control logic (123) within the device.

The control logic (120) within the Host PC assembles the notified isochronous data and transmits it as a Data Payload packet to the LEX subsystem. The control logic (121) within the LEX subsystem forwards the Data Payload packet to the REX subsystem. The control logic (122) in the LEX subsystem further forwards the Data Payload packet to the device. The information is received by the control logic (123) within the device.

Figure 11 provides an algorithm for implementing isochronous transfers at the Local Expander (4). In the embodiment of the invention described in

Figure 6, said algorithm is implemented in hardware by LEX Controller (51). (It will be apparent to those skilled in the art that this implementation is not unique and that other mechanisms for implementing said algorithm are possible.) In the following description, the inbound direction refers to packets travelling from a peripheral device and towards a host controller; the outbound direction refers to packets travelling from a host controller and towards a peripheral device.

According to the invention, the algorithm of Figure 11 is required to implement the processing functions represented by processing blocks of Figure 8 (101, 105 & 109), and the processing block (121) of Figure 10.

On initial power-up and after a reset, the system enters Idle state (200) where it waits for a message (USB packet) to be received. When a packet is received, the Packet Identifier (PID) field within the packet is examined to determine what type of packet has been received and what action is required to process said packet.

If the received packet (201) is of type IN, then an identical packet (202) is transmitted. The system then examines (203) its buffer memory to determine whether a stored DATA packet from the device addressed by the IN request is already present in memory. If no such stored DATA packet is present in memory, the system then returns to the idle state (200). If said stored DATA packet is present in memory, the system retrieves (204) said stored packet from memory and sends (205) said packet to the host as a packet of type DATA. It then returns to the Idle state (200).

If the received packet (206) is of type DATA and is travelling in the inbound direction, the system saves (207) said data packet in its buffer memory. The system then returns to the Idle state (200).

If the received packet (208) is of type OUT Addr, the system retransmits the packet (209) packet and returns to the Idle state (200).

If the received packet (210) is of type DATA and is travelling in the outbound direction, the system retransmits packet (211) and returns to the Idle state (200).

Figure 12 provides an enhanced algorithm for implementing isochronous transfers at the Local Expander according to the invention described in Figure 9.

This algorithm is essentially identical to that described in Figure 11, other than in the way in which it handles the situation wherein the Host issues a request for data and the LEX does not yet possess said data to return to the host. This situation may occur on the first request of an isochronous input session.

In Figure 12, if the received packet (201) is of type IN, then an identical packet (202) is transmitted. The system then examines (203) its buffer memory to determine whether a stored DATA packet from the device addressed by the IN request is already present in memory. If no such stored DATA packet is present in memory, the system generates (212) a synthetic DATA packet and transmits (213) said generated packet to the host within the 16 bit-times permitted by the USB protocol. If said stored DATA packet is present in memory, the system retrieves (204) said stored packet from memory and sends (205) said packet to the host as a packet of type DATA. It then returns to the Idle state (200).

If the received packet (206) is of type DATA and is travelling in the inbound direction, the system saves (207) said data packet in its buffer memory. The Packet Aging Flag associated with the newly saved packet is reset (214) for reasons that will be described in the context of Figure 13. The system then returns to the Idle state (200).

Figure 13 is a logic diagram of a further enhancement to the LEX Controller enabling vestigial packets to be removed. Said vestigial packets can occur during Isochronous Input transfers when the Host PC decides to terminate a session but the LEX Controller already possesses an inbound data packet belonging to said session. This situation is illustrated, for example, in Figure 8 by packet Data Payload_3.

Under the USB Specification, the start of every frame is marked by a unique Start Of Frame (SOF) signal. The embodiment described in Figure 13 uses this SOF signal to identify and discard packets that are no longer required. Processing commences when SOF signal (221) is received by the Local Expander. A search of local buffer memory is commenced by setting the context to the first buffer (222). The Packet Aging Flag of the packet pointed to by the current context is examined (223). If the Packet Aging Flag is already set, then

the packet in the buffer is discarded (224). If the Packet Aging Flag is not set, then the Packet Aging Flag is set (225) to ensure that the packet will be discarded in the next frame if it has not been transmitted by then.

The aforesaid process is then repeated by setting the context to the next buffer (227) and continuing until all buffers have been checked, as detected by test (226).

Note that as an additional precaution to prevent the premature discarding of vestigial packets, the packet Aging Flag is also reset by step (214) of Figure 12 whenever a data packet is stored in the buffer memory of the LEX Controller.

Figure 14 provides an algorithm for implementing isochronous transfers at the Remote Expander. In the embodiment of the invention described in Figure 7, said algorithm is implemented in hardware by REX Controller (61). (It will be apparent to those skilled in the art that this implementation is not unique and that other mechanisms for implementing said algorithm are possible.) In the following description, the inbound direction refers to packets travelling from a peripheral device and towards a host controller; the outbound direction refers to packets travelling from a host controller and towards a peripheral device.

According to the invention, the algorithm of Figure 14 is required to implement the processing functions represented by the processing blocks (102), (106) & (110) of Figure 8, and the processing block (122) of Figure 10.

On initial power-up and after a reset, the system enters Idle state (230) where it waits for a message (USB packet) to be received. When a packet is received, the Packet Identifier (PID) field within the packet is examined to determine what type of packet has been received and what action is required to process said packet.

If the received packet (231) is of type IN, the system retransmits (232) said IN packet and returns to the Idle state (230).

If the received packet (233) is of type DATA and is travelling in the inbound direction, the system retransmits (234) said data packet and returns to the Idle state (230).

If the received packet (235) is of type OUT, the system retransmits (236) said out packet and returns to the Idle state (230).

If the received packet (237) is of type DATA and is travelling in the outbound direction, the system retransmits (238) said data packet and returns to the Idle state (230).

Figure 15 provides an enhanced algorithm for implementing isochronous transfers at the Remote Expander. Under certain conditions, there is a risk that packets sent from the Remote Expander and arriving at the Local Expander may not be in the order expected by the Local Expander. The enhancement described in Figure 15 adds an Address field to packets sent in the inbound direction so that the Local Expander can be certain of the origin of said packets.

According to the enhancement, when an IN packet is received (231) by the REX Controller, the Address it contains is stored in memory (239). The IN packet is then retransmitted as before (232) and the system returns to the Idle state (230). When the system receives the next DATA packet travelling in the inbound direction (233), the system retrieves the Address stored in memory (240) and includes this information with the DATA packet that it retransmits (234) to the LEX. The system returns to the Idle state (230).

Having described specific embodiments of the present invention, it will be understood that modifications thereof may be suggested to those skilled in the art, and it is intended to cover all such modifications as fall within the scope of the appended claims. Additionally, for clarity and unless otherwise stated, the word "comprise" and variations of the word such as "comprising" and "comprises", when used in the description and claims of the present specification, is not intended to exclude other additives, components, integers or steps.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for transmitting a time relevant data stream between a host controller and a peripheral device over an extended distance; said method comprising:

a. feeding a first original, outgoing digital signal from a host controller to a local expander unit;

b. optionally converting said outgoing digital signals into a converted outgoing signal having a format suitable for transmission over extended distances;

c. transmitting either said outgoing digital signal or said converted outgoing signal, as a outgoing transmission signal, over a signal distribution system;

d. receiving said outgoing transmission signal at a remote expander unit;

e. optionally converting said outgoing transmission signal to said first original outgoing digital signal;

f. delivering said first original outgoing digital signal from said remote expander to at least one peripheral device;

g. receiving, at said remote expander, a reply digital signal from said peripheral device;

h. optionally converting said reply digital signal into a converted reply signal having a format suitable for transmission over extended distances;

i. transmitting said reply digital signal or said converted reply signal as a reply transmission signal over said signal distribution system;

j. receiving said reply transmission signal at said local expander;

k. optionally converting said reply transmission signal to said original reply digital signal;

l. storing said reply digital signal as a stored reply digital signal until the receipt of a subsequent original, outgoing digital signal from said host controller, which subsequent signal is the same as, or similar to, said first original outgoing digital signal; and

m. forwarding said stored reply digital signal to said host controller in response to said subsequent original outgoing digital signal.

2. A method as in claim 1 wherein said original digital signals conform to the USB Specification; and said reply digital signal represent isochronous data.

3. A method as in claim 1 wherein said extended distance exceeds 5 meters.

4. A method as claimed in Claim 3 wherein said extended distance exceeds 30 meters.

5. A method as claimed in Claim 4 wherein said extended distance exceeds 100 meters.

6. A method as in claim 1 wherein said signal distribution system utilizes unshielded twisted pair (UTP) wiring.

7. A method as claimed in Claim 1 wherein said method provides a method for transmission of isochronous data according to the USB Specification wherein isochronous data is transmitted from a peripheral device and is received by a host controller, said method comprising:

a. transmitting a request for isochronous data from a host controller to a local expander;
b. forwarding said request for isochronous data from said local expander to a remote expander over a signal distribution system;
c. delivering said forwarded request for isochronous data to at least one peripheral device;
d. transmitting the requested isochronous data from said peripheral device to said remote expander;

e. forwarding said requested isochronous data from said remote expander to said local expander over said signal distribution system;

f. storing said requested isochronous data in a packet buffer at said local expander;

g. transmitting a subsequent request for isochronous data from said host controller to said local expander;

h. receiving said subsequent request for isochronous data at said local expander; and

I. retrieving the stored isochronous data from said local expander;

II. delivering said stored isochronous data to said host controller;

III. forwarding said subsequent request for isochronous data from said local expander to said remote expander over said signal distribution system; and

IV. repeating steps (c) through (h) for said subsequent request and any further subsequent requests for isochronous data.

8. A method as claimed in Claim 7 additionally comprising the following steps after step (b) of Claim 7, namely:

i. Determining whether said local expander already possesses said requested isochronous data;

ii. Generating a synthetic data packet if no such requested isochronous data is present; and

iii. Delivering said synthetic isochronous data to said host controller.

9. A method as claimed in Claim 7 additionally comprising the following step after step (c) of Claim 7, namely:

i) Storing the address of the requested peripheral device at said remote expander unit;

and further comprising the following steps after step (d) of Claim 7, namely:

i) Retrieving the address of said requested peripheral device at said remote expander unit; and

ii) Adding said retrieved address to said requested isochronous data.

10. A method as claimed in Claim 7 wherein vestigial packets are removed from the system, said method comprising:

i) Detecting when a new frame has begun;

ii) Examining the properties of each packet buffer;

iii) Determining whether the data packet contained in said examined packet buffer has been stored for at least one complete frame period;

iv) Discarding said contained data packet if said contained data packet has been stored for at least one complete frame period; and

v) Repeating steps (i) through (iv) for each packet buffer in the system.

11. A method as claimed in Claim 1 wherein said host controller is a PC, and said peripheral device a camera, a mouse, a keyboard, a monitor or a speaker or speakers.

12. An apparatus for transmission of a digital signal over an extended distance comprising:

a local expander comprising means for receiving a request for a time relevant data signal from a host controller which host controller is connected to said local expander;

means in said local expander for generating an outgoing transmission signal;

means in said local expander for sending said outgoing transmission signal to a remote expander, which signals are sent over a signal distribution system;

a remote expander comprising means for receiving said outgoing transmission signal;

means in said remote expander for generating a digital signal from said outgoing transmission signal;

means in said remote expander for forwarding said digital signal to at least one peripheral device, which peripheral device is connected to said remote expander;

means in said remote expander for receiving inbound digital signals from said peripheral devices;

means in said remote expander for converting said inbound digital signals to an inbound transmission signal;

means in said remote expander for sending said inbound transmission signal to said local expander, which signals are sent over said signal distribution system;

means in said local expander for receiving said inbound transmission signal;

means in said local expander for generating a digital signal from said inbound transmission; and

means in said remote expander for forwarding said digital signal to said host controller.

13. An apparatus as claimed in Claim 12 wherein said local expander additionally comprises:

means for storing said inbound signal as a stored inbound signal;

means for analysing said digital signal from said host controller to recognize a subsequent request for transmission of said time relevant digital signal; and

means for sending said stored inbound signal to said host controller in response to said subsequent request.

14. An apparatus as claimed in Claim 12 or 13 wherein said time relevant signal is a digital signal which conforms to the USB Specification; and said time relevant signal represent isochronous data.

15. An apparatus as in claim 12 or 13 wherein said extended distance exceeds 5 meters.

16. An apparatus as claimed in Claim 15 wherein said extended distance exceeds 30 meters.

17. An apparatus as claimed in Claim 16 wherein said extended distance exceeds 100 meters.

18. An apparatus as claimed in Claim 12 wherein said signal distribution system utilizes unshielded twisted pair (UTP) wiring.

19. An apparatus as claimed in Claim 12 wherein said host controller is a PC, and said peripheral devices is a camera, a mouse, a keyboard, a monitor or a speaker or speakers.

Abstract

The present invention provides a method and apparatus to be used to extend the range of a standard USB devices when utilizing isochronous data streams. An extended range hub is provided which comprises a Local Expander (LEX) and a Remote Expander (REX) which can be separated by up to, for example 100 metres. The method and apparatus permits USB devices to be more conveniently located and used.

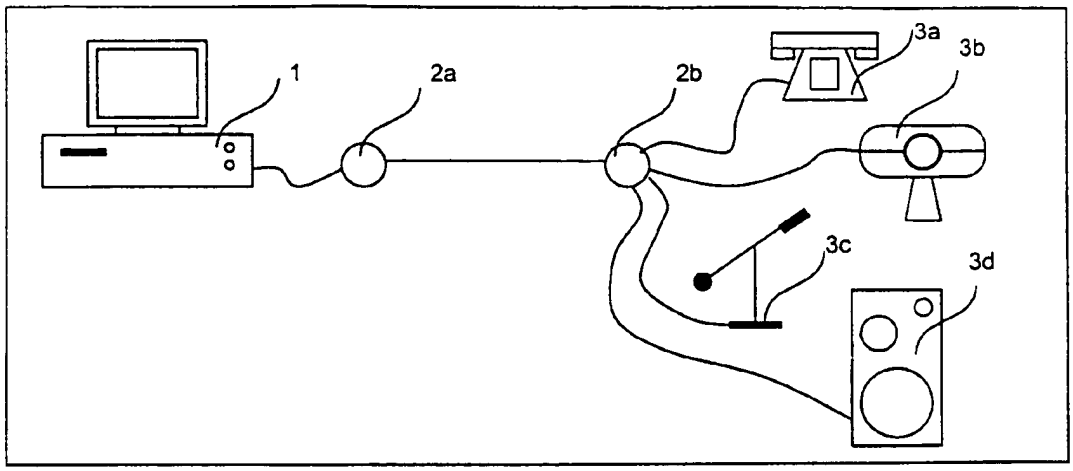

Figure 1

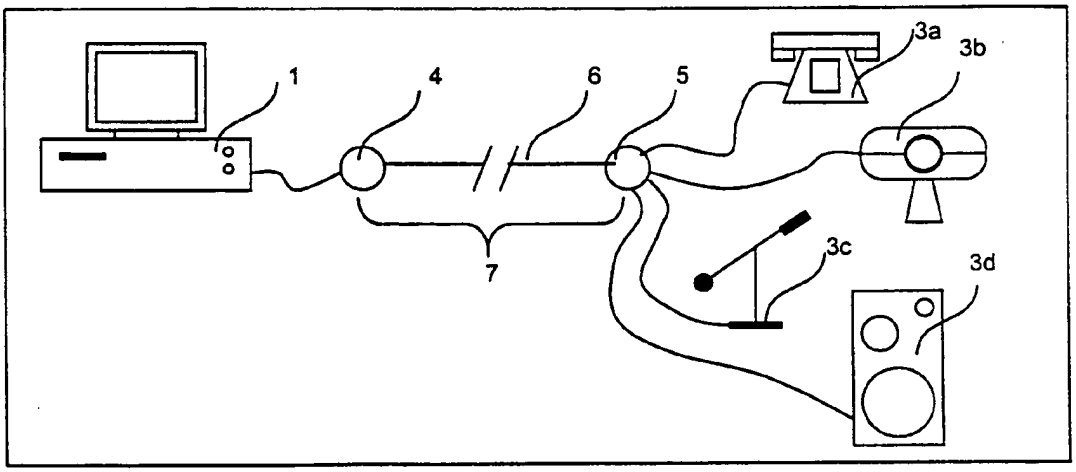

Figure 2

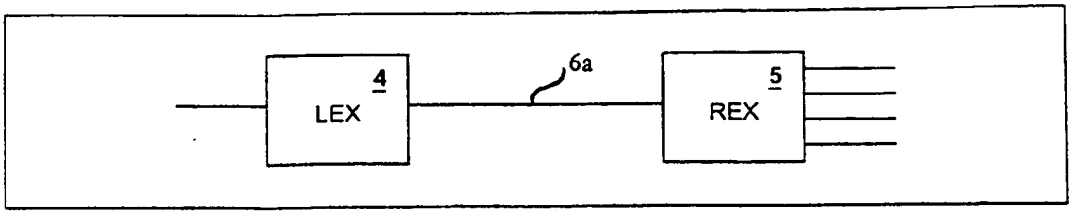

Figure 3

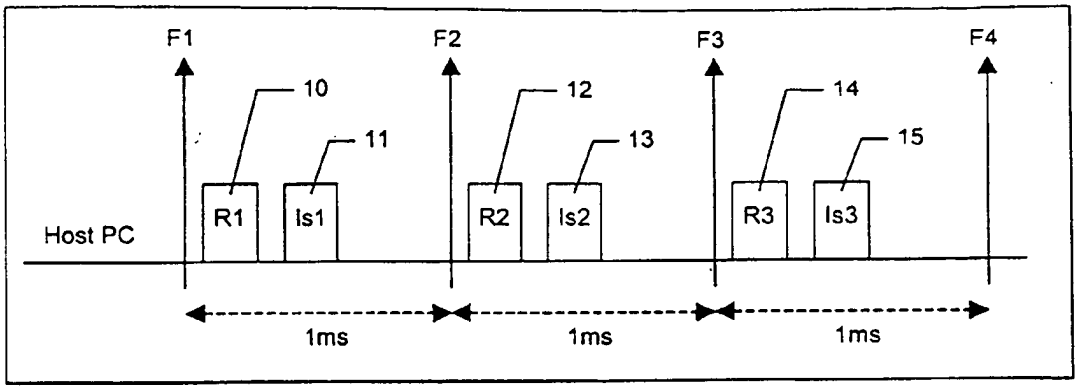

Figure 4

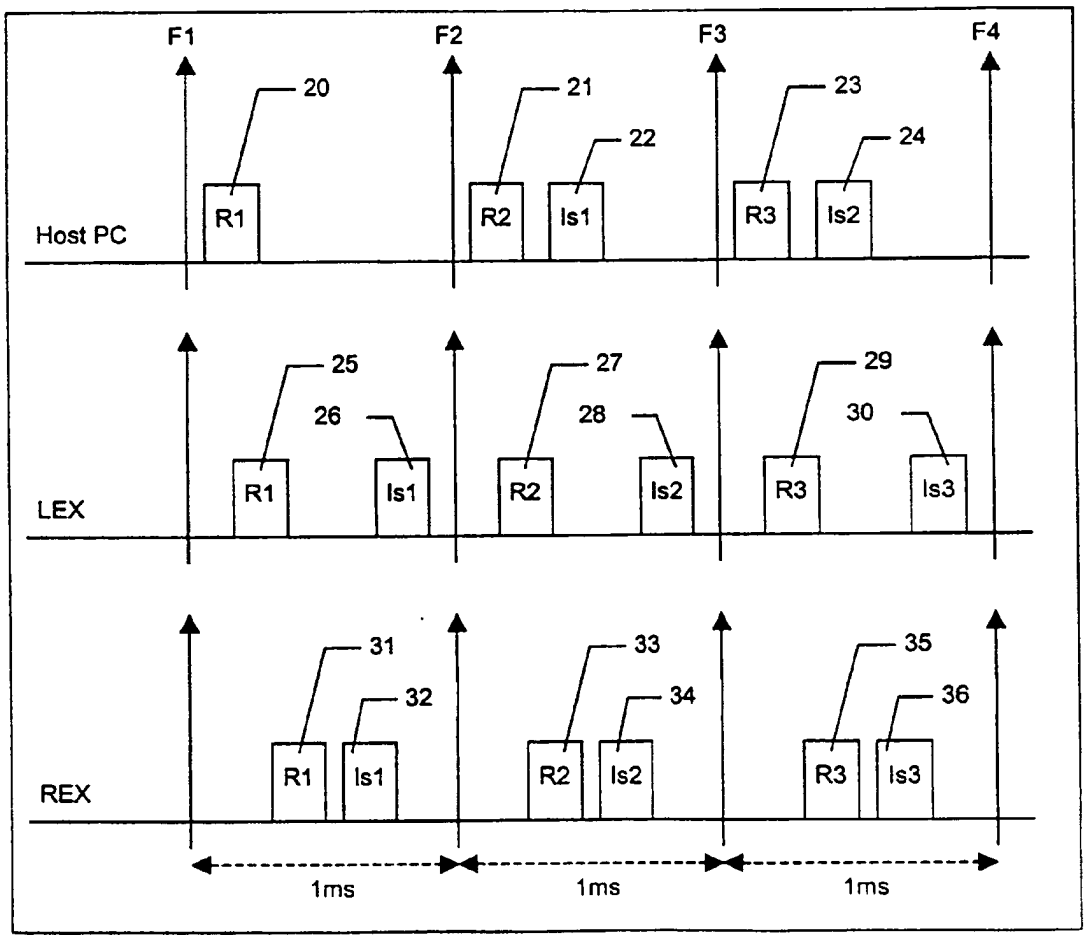

Figure 5

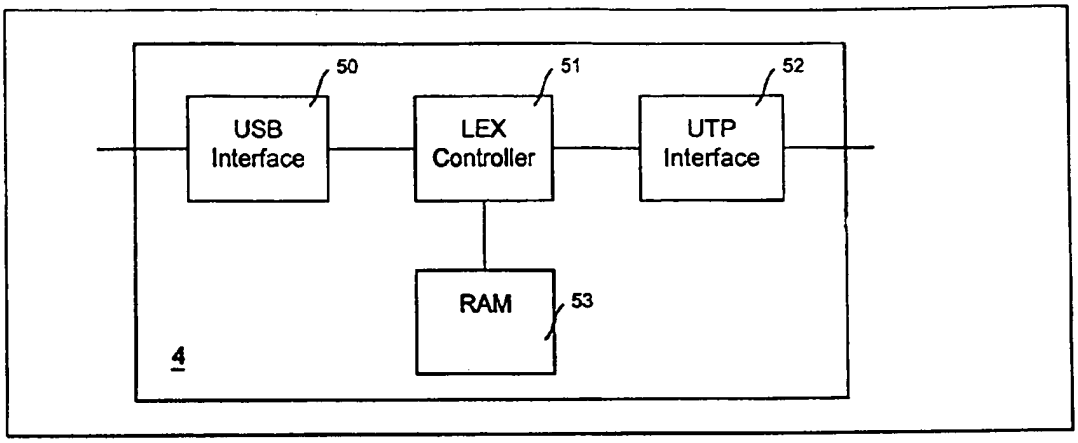

Figure 6

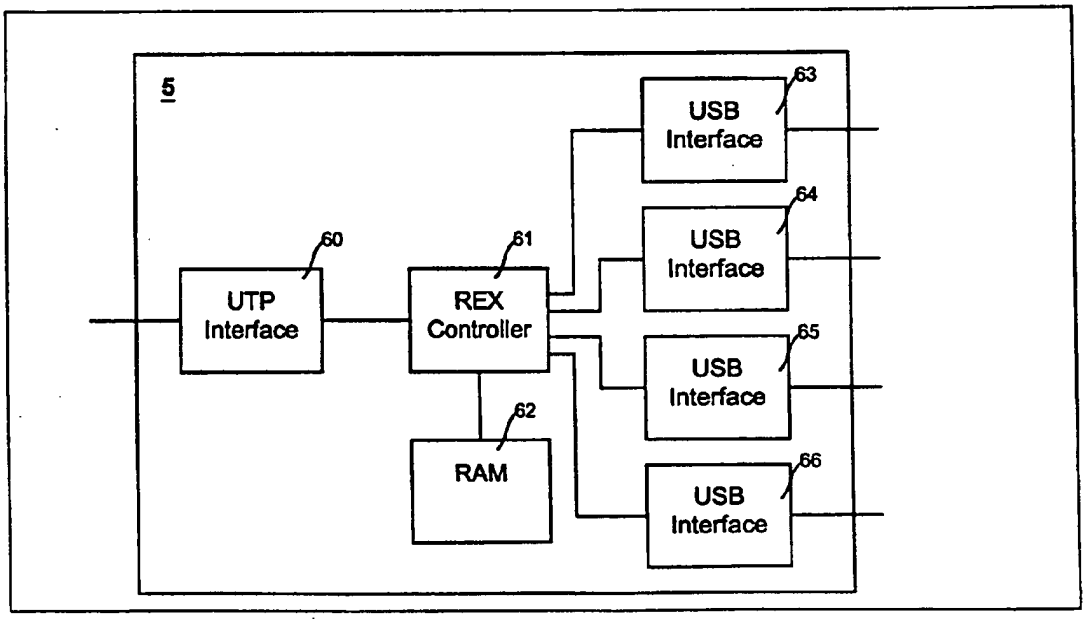

Figure 7

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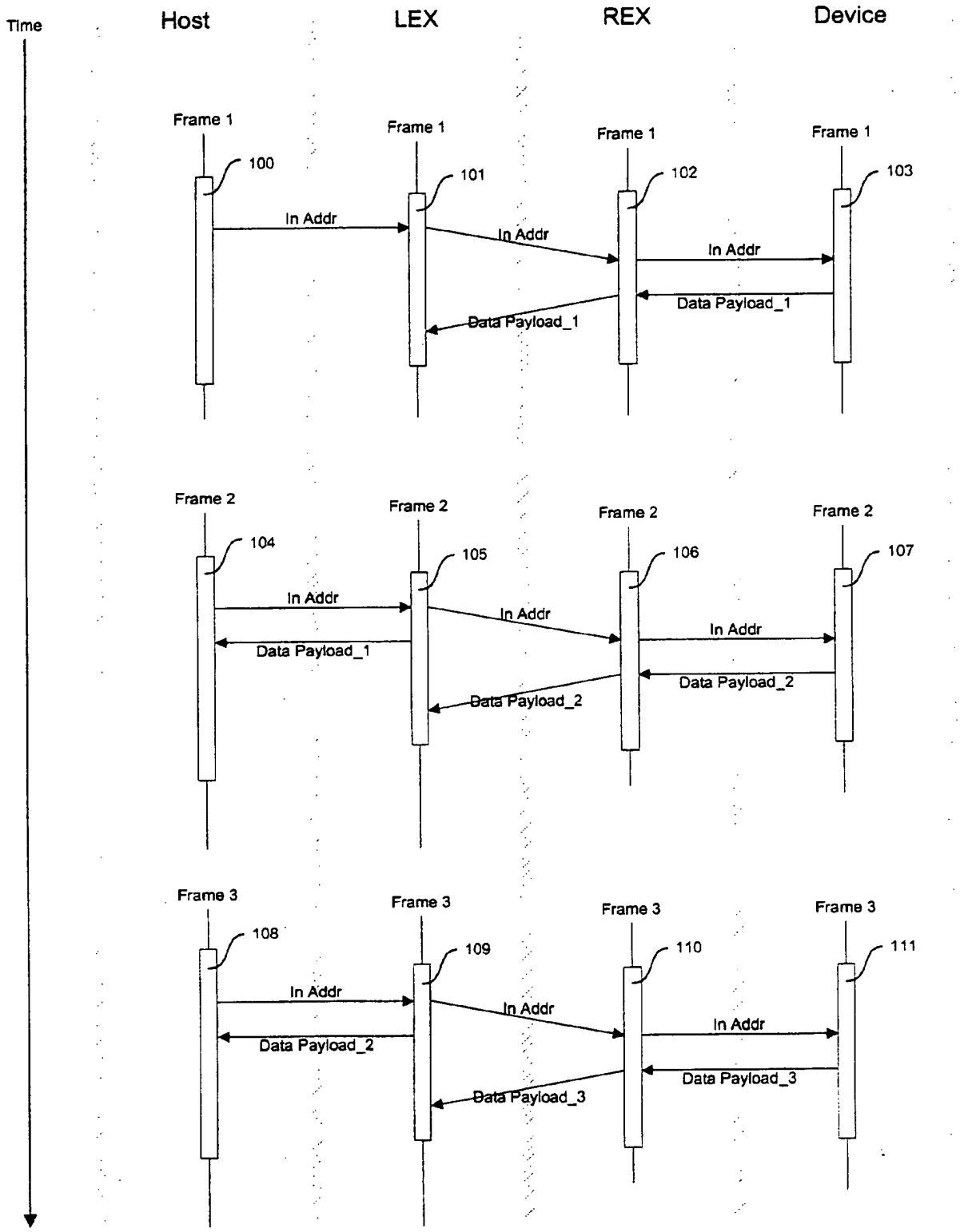

Figure 8

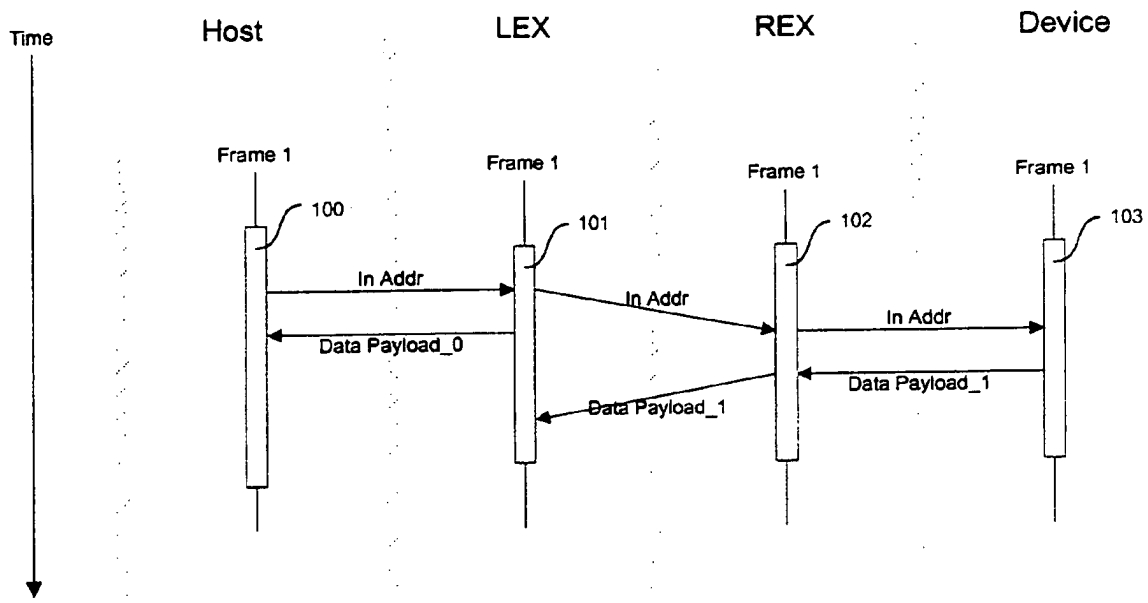
Time
Host
LEX
REX
Device
Frame 1
Frame 1
Frame 1
Frame 1
100
101
102
103
In Addr
In Addr
In Addr
Data Payload_0
Data Payload_1
Data Payload_1

Figure 9

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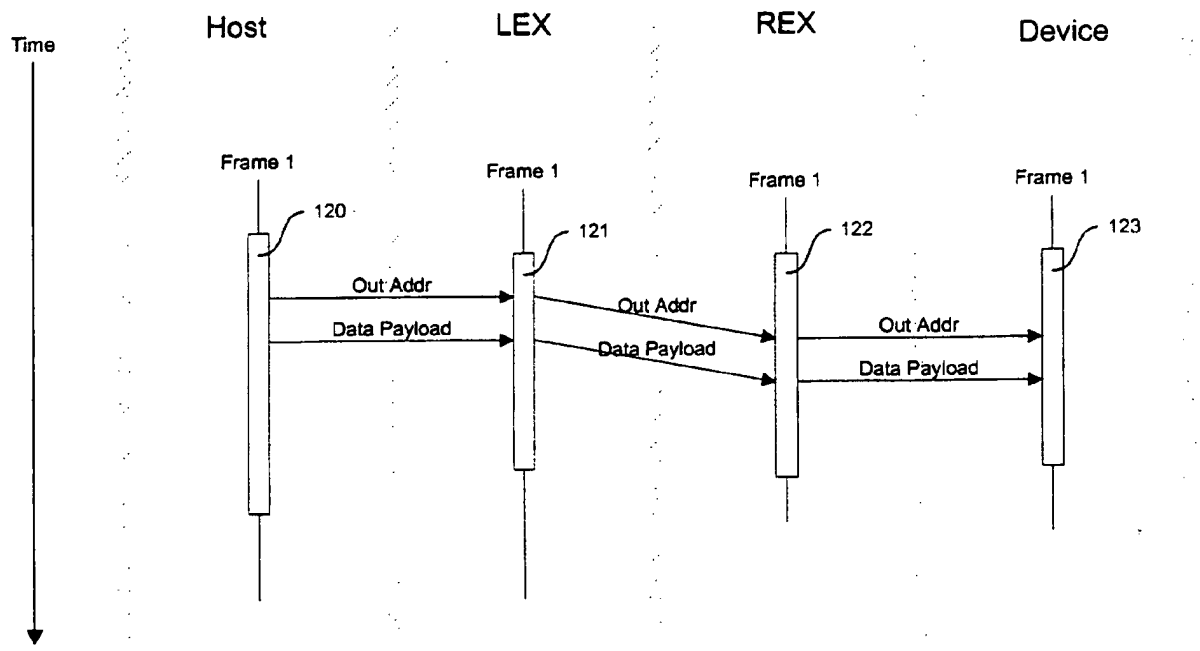

Figure 10

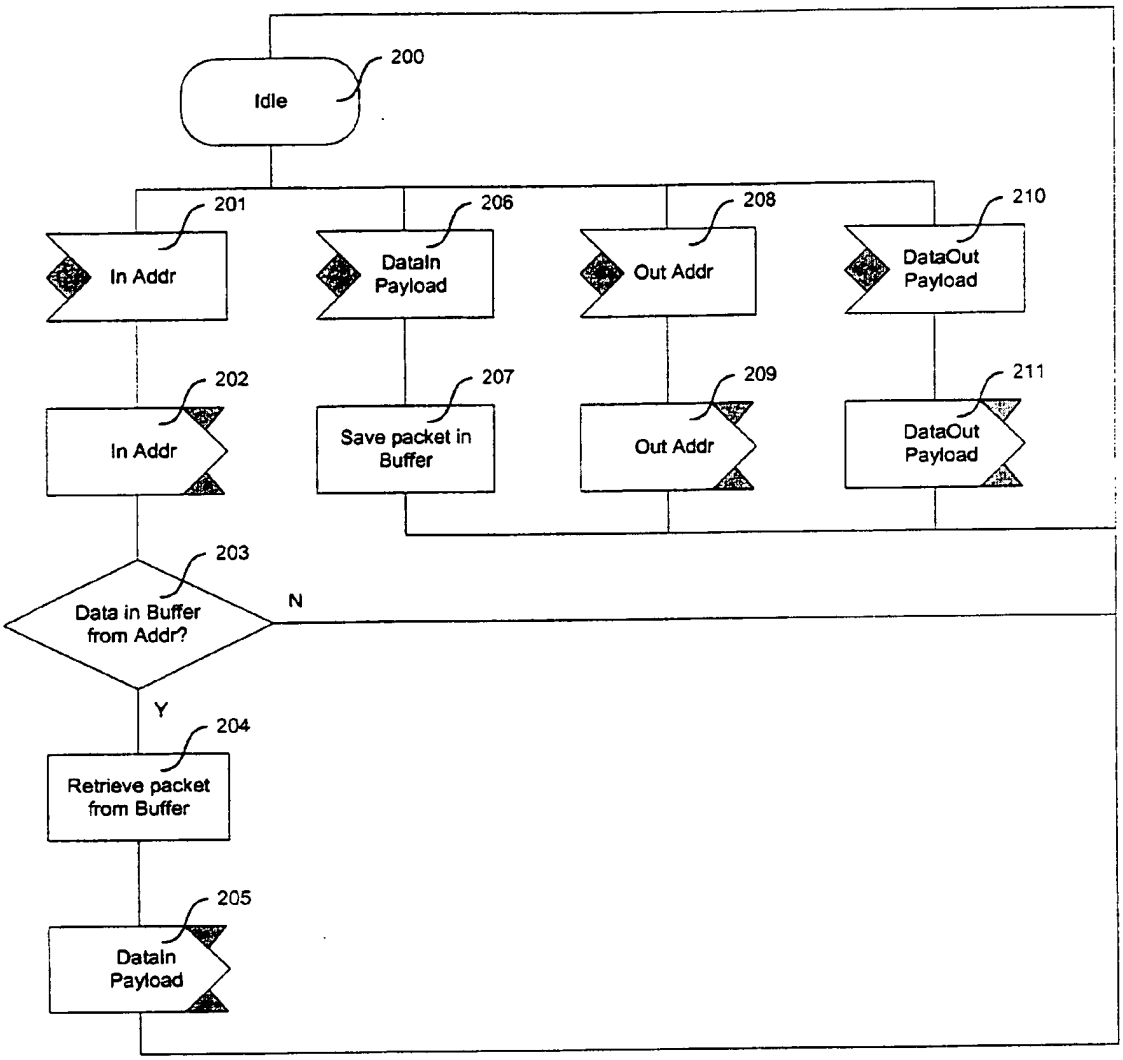
200
Idle
201
In Addr
206
DataIn Payload
208
Out Addr
210
DataOut Payload
202
In Addr
207
Save packet in Buffer
209
Out Addr
211
DataOut Payload
203
Data in Buffer from Addr?
N
Y
204
Retrieve packet from Buffer
205
DataIn Payload

Figure 11

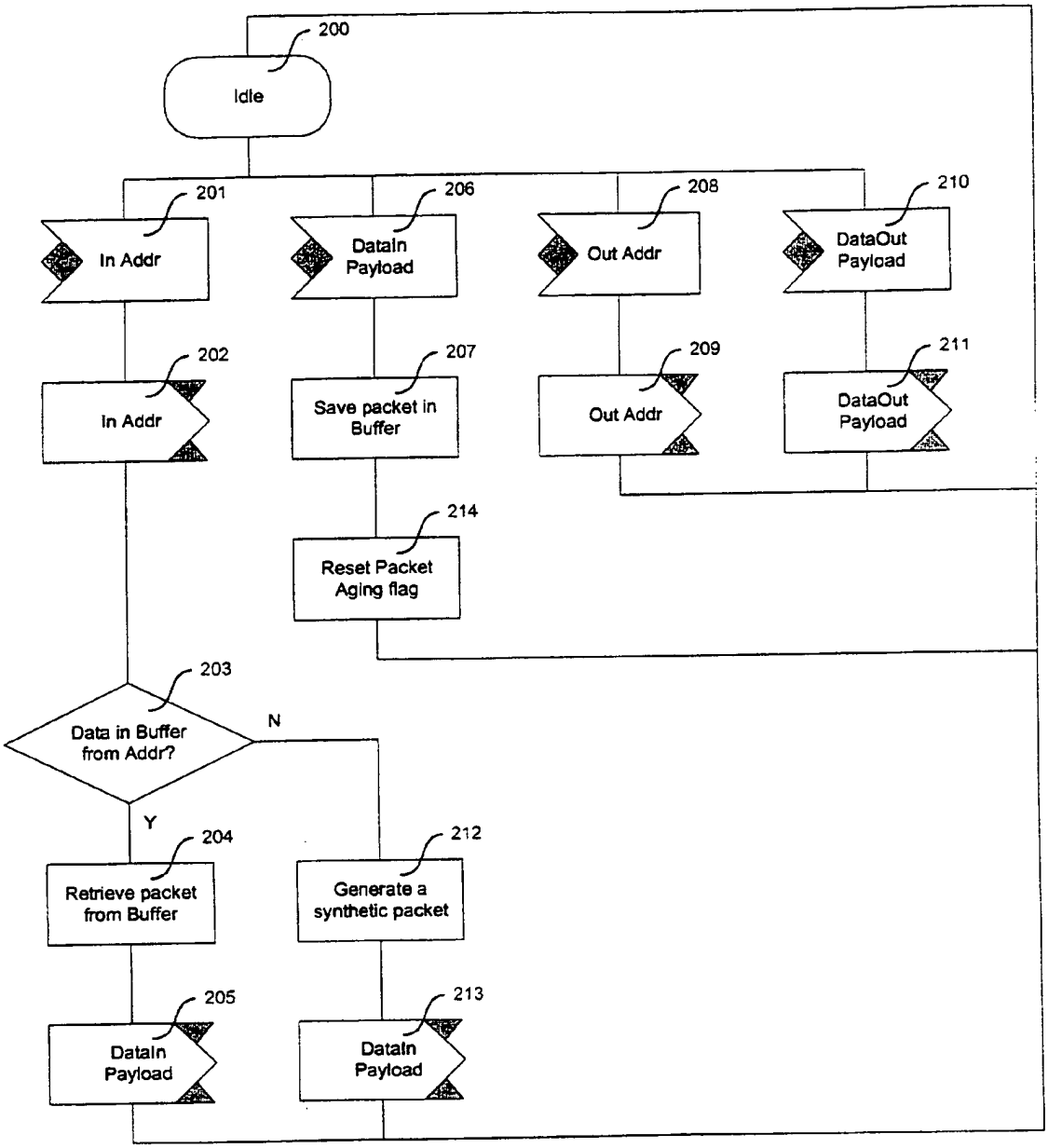
200
Idle
201
In Addr
206
DataIn Payload
208
Out Addr
210
DataOut Payload
202
In Addr
207
Save packet in Buffer
209
Out Addr
211
DataOut Payload
214
Reset Packet Aging flag
203
Data in Buffer from Addr?
N
Y
204
Retrieve packet from Buffer
212
Generate a synthetic packet
205
DataIn Payload
213
DataIn Payload

Figure 12

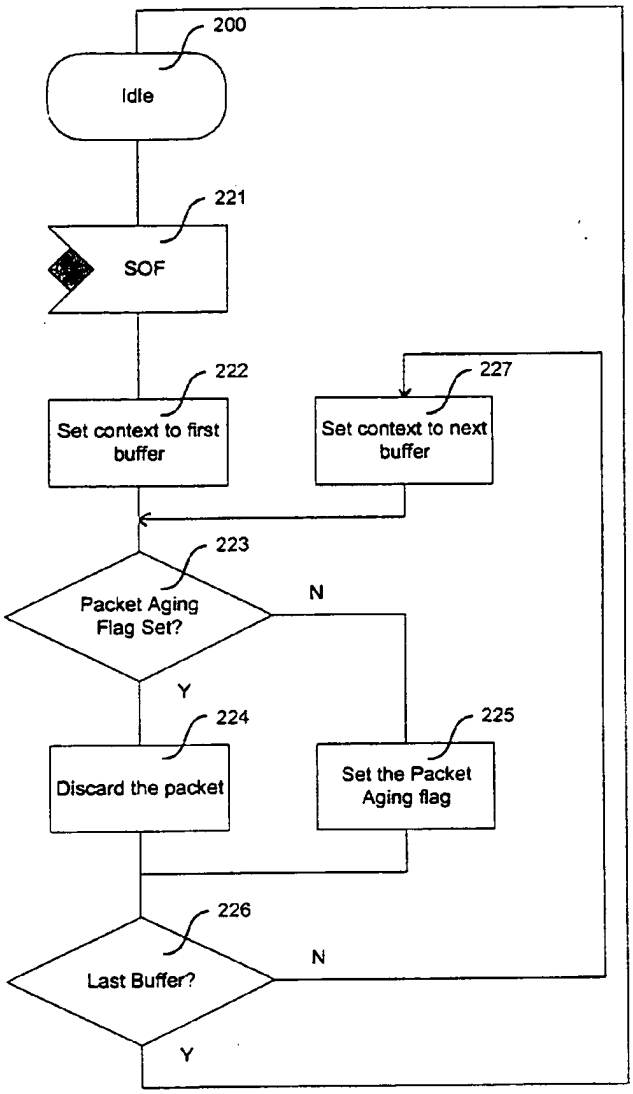
200
Idle
221
SOF
222
Set context to first buffer
227
Set context to next buffer
223
Packet Aging Flag Set?
N
Y
224
Discard the packet
225
Set the Packet Aging flag
226
Last Buffer?
N
Y

Figure 13

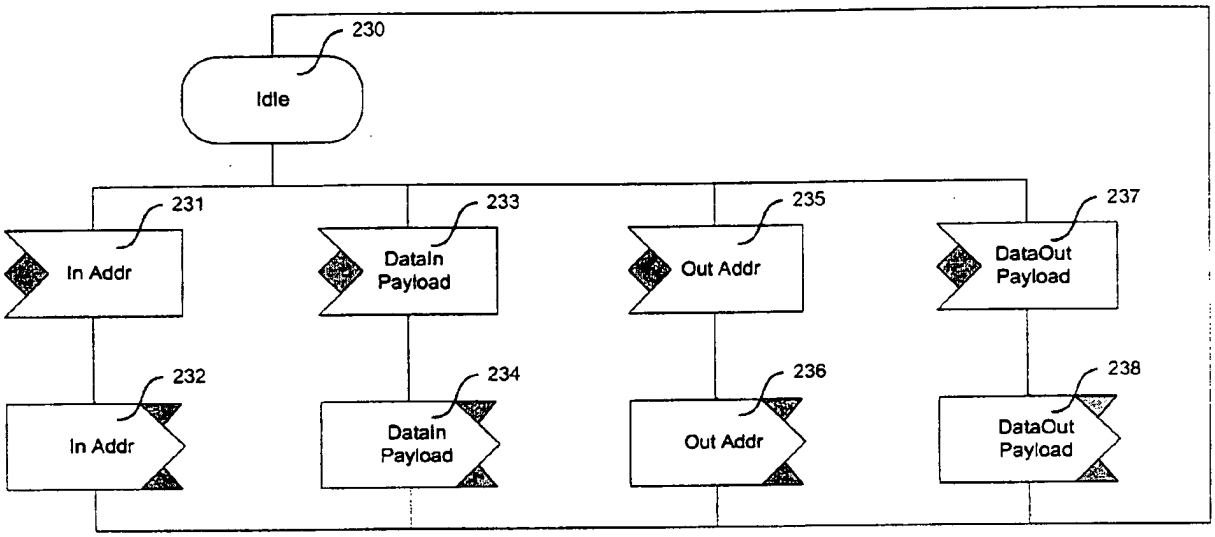
230
Idle
231
In Addr
232
In Addr
233
DataIn Payload
234
DataIn Payload
235
Out Addr
236
Out Addr
237
DataOut Payload
238
DataOut Payload

Figure 14

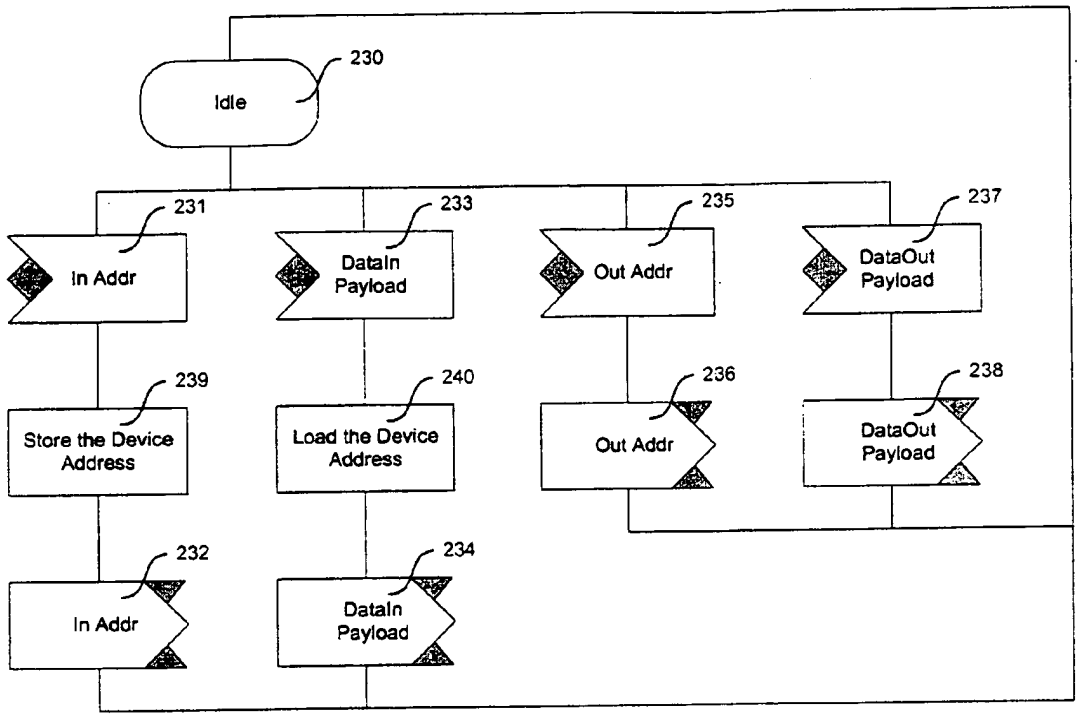
230
Idle
231
In Addr
233
DataIn Payload
235
Out Addr
237
DataOut Payload
239
Store the Device Address
240
Load the Device Address
236
Out Addr
238
DataOut Payload
232
In Addr
234
DataIn Payload

Figure 15